DIVISION S-5—PEDOLOGY

Classification of Forested Histosols in Southeast Alaska

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ABSTRACT

Organic soils are an important substrate for cycling carbon between terrestrial and atmospheric pools. The degree of decomposition of organic soil material influences the physical and chemical characteristics that control the carbon cycles in these soils. Although organic soils are abundant in southeast Alaska, little information is available on the state of decomposition or variability within organic soil mapping units. Determination of physical (fiber content) and chemical (sodium pyrophosphate extract color, SPEC) decomposition is used to classify organic soils and subsequently establish map units. The purpose of this study is to provide physical and chemical decomposition data to better characterize and classify forested organic soils in southeast Alaska and to improve our understanding of the distribution of fiber within these soils. Fiber content and pyrophosphate color were determined on 115 samples from 23 organic soils from throughout the Tongass National Forest. These samples show that complexes of hemic and sapric suborders mapped in the Tongass Soil Survey are dominantly hemic. Some fiber analyses differ considerably from statements in descriptions of established series in the Tongass Soil Survey. Physical decomposition of the fibers is in the hemic range, but chemical decomposition indicated by SPEC is sapric due to accumulation of soluble organic matter by water movement down steep slopes as well as in situ decomposition. Suborder classes provide a means to incorporate appropriate decomposition levels into existing soil series.

The classification of organic soils in the U.S. system of soil taxonomy was developed to provide criteria that can be determined by visual observations and field office tests. The system outlined by McKinzie (1974) was first established in the 1974 *Keys to Soil Taxonomy*. It was based on the work of Farnham and Finney (1965), who reviewed much of the literature on organic soil classification available at that time. Soil taxonomy recognizes three classes of decomposition for organic soil materials at the suborder level: slightly decomposed fibric material, moderately decomposed hemic material, and well decomposed sapric material (Lynn et al., 1974; McKinzie, 1974; Soil Survey Staff, 1999).

An important physical, chemical, and botanical characteristic of peat is the degree of decomposition of the organic material. The decomposition state of organic soils influences the flow and retention of water (Boelter, 1964, 1969), bulk density (Karesniemi, 1972; Levesque and Dinel, 1977; Nichols and Boelter, 1984), organic C accumulation (Frazier and Lee, 1971), nitrogen content (Sowden et al., 1978; Williams, 1983), cation exchange capacity (Levesque et al., 1980), and respiration (Norden et al., 1992). Therefore, characterizing the fiber content and SPEC is needed to accurately predict these physical and chemical processes occurring in the soil, and to classify the soils in soil taxonomy.

Concern about global carbon cycles has renewed the focus of research on the physical and chemical properties of northern peatlands (Gorham, 1991). The cycling of carbon gases (CO_2 and CH_4) between peatlands and the atmosphere is closely related to these properties (Wieder and Yavitt, 1991; Buttler et al., 1994). A first step in estimating carbon fluxes is to estimate the carbon storage in organic soils. The state of organic matter decomposition can provide indications of the amount and quality of carbon stored in peat. Decomposition is correlated with chemical variables used to predict carbon mineralization in peat (Bridgham, 1998; Bridgham et al., 2000).

Peatlands cover 15% of the Tongass National Forest; however, few analytical measurements of fiber content or SPEC were done during the soil survey of the area. The lush woody and moss growth attests to a relatively high balance of carbon sequestration compared with most ecosystems. In general, forested uplands and wetlands sequester CO_2 and act as a sink for carbon. Stagnant wetlands produce CH_4 that is released to the atmosphere. Determining the peatland areas that act as sinks or sources for carbon can aid in establishing carbon budgets for northern peatlands. Rapid water transmission on steep slopes in southeast Alaska may promote aeration and minimize CH_4 production, leading to a relative increase in carbon sequestration.

A recent study of tree growth on peatlands in southeast Alaska (Julin and D'Amore, 2002) focused on four extensive organic soil series: Maybeso (loamy-skeletal, mixed, euic, Terric Cryosaprists), Kaikli (euic Lithic Cryosaprists), Karheen (euic Typic Cryosaprists), and Kitkun (euic, shallow Lithic Cryosaprists). The detailed soil pedon descriptions and fiber analyses conducted on these soils revealed that most pedons had hemic materials in the taxonomic control section and were outside the range of fiber content for the series. Therefore, we reviewed data for fiber analyses completed on 6 pedons during the Tongass soil survey and found that most of these samples were determined to be sapric material. The information from the original survey was very limited, and we have conducted additional analyses

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Abbreviations: SPEC, sodium pyrophosphate extract color.

to expand the number of samples for organic soils in southeast Alaskan Histosols in order to refine our interpretation of fiber content in these soils. We determined fiber content and SPEC of samples from 23 pedons from forested wetland sites throughout southeast Alaska. The purpose of the present study is to provide fiber and SPEC data to improve characterization and classification of forested organic soils in southeast Alaska and to increase our understanding of the distribution of fiber within these soils.

MATERIALS AND METHODS

Setting

Southeast Alaska, ≈8.5 million ha, extends ≈800 km from Dixon Entrance in the south to Yakutat Bay in the north. It is part of the Pacific mountain system (Wahrhaftig, 1965) and is characterized by steep mountainsides and glacial valleys (Fig. 1). The region has a perhumid rainforest with moist, cool summers, and mild winters (Alaback, 1982). Rain falls all year, 1500 to 5000 mm annually, with greatest accumulation in September and October (Helmers, 1974). The Tongass National Forest occupies 6.9 million ha. Native corporations, the State of Alaska, and private individuals own the remainder.

Tongass Soil Survey

Organic soil sample data in this paper came from two sources. Data from six pedons were obtained from the original soil survey data for the Tongass. All of these pedons were located in the same geographic region on the Stikine administrative area of the Tongass. In addition, 23 pedons from 21 forested sites throughout the entire region were described and sampled from 1995 to 1998. The additional sampling increased the total number of pedons sampled for organic soil analysis on the forest to 29. The additional samples represent a broader distribution of organic soils in the region.

Information for the Tongass soil survey came from the soil correlation reports and laboratory data from the National Soil Survey Laboratory and the University of Idaho. The final soil correlation contains 66 soil series. Included are 15 series of Histosols that occur on forested and nonforested peatland: three folists, 1 fibrist, 1 sphagnofibrist, 3 hemists, and 7 saprists. Six of the 15 Histosol series are discussed in this paper. Four of these series are closely associated with forest vegetation in the soil survey: the Maybeso, Kaikli, Kina (dysic, Typic Cryohemists), and Kushneahin (dysic, Typic Cryosaprists). The Maybeso, Kaikli, and Kina series occur frequently on forested peatlands throughout southeast Alaska. Maybeso and Kaikli have an overstory of western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], western red cedar (*Thuja plicata*, Donn ex D. Don), Sitka spruce [*Picea sitchensis* (Bong.) Carriere], and Alaska yellow-cedar [*Chamaecyparis nootkatensis* (D. Don) Spach], a shrub layer of blueberry (*Vaccinium* spp.), and rusty menziesia (*Menziesia ferruginea* Sm.), and an herb layer of skunk cabbage [*Lysichiton americanus* Hulten & H. St. John], and marsh marigold (*Caltha palustris* L.). Hemist soils, such as Kina, and some saprist soils, such as the Kushneahin series, have an overstory that varies from no trees to lodgepole pine [*Pinus contorta* Douglas ex Loudon], western hemlock, Alaska yellow-cedar, and an understory of sedges (*Carex* spp.), deer cabbage {*Fauria crista-galli* (Menzies ex Hook.) Makino [syn. *Nephrophyllidium crista-galli* (Menzies ex Hook.) Gilg]}, mosses (*Sphagnum* spp.), and ericacious plants.

Soil Sampling and Analysis

Soil pits were excavated and described according to the Soil Survey Manual (Soil Survey Division Staff, 1993). Three samples were taken from each of 115 soil horizons in 23 pedons at 21 forested sites throughout the region. All samples were

Fig. 1. Photo of a typical landscape sequence from the Tongass National Forest, southeast Alaska.

taken in areas covered by the Tongass soil survey. Duplicate undisturbed 5-cm soil cubes for bulk density were weighed while wet, oven dried at 105 °C, and weighed again. Field-state bulk density equals dry weight divided by moist volume. The samples were then ashed at 400 °C to determine mineral content (Soil Survey Laboratory Staff, 1996). The bulk density of the organic framework was calculated by subtracting the weight of the mineral component from the total dry weight prior to dividing by the moist volume (Lynn et al., 1974). The third sample was analyzed for fiber content and SPEC according to Lynn et al. (1974) and Soil Survey Division Staff (1975). Field moist samples were packed in a half-syringe at an initial volume of 2.5 cm^3 for determination of unrubbed fiber and SPEC. Pyrophosphate color was determined by soaking 2.5 cm^3 (packed half-syringe) of sample in a saturated solution of sodium pyrophosphate for 24 h. A strip of chromatographic paper was then added to the solution and allowed to absorb the solution for ≈5 min. The color of the strip was compared with a Munsell color chart and reported as SPEC. The sample was then rinsed through a 100-mesh sieve adjusted to deliver 200 to 300 mL in 5 s. Once the residue was free of sapric material, the residue on the screen was collected, returned to the half-syringe, and blotted to the original moisture content. The volume of fiber remaining was reported as the percentage of unrubbed fiber. The sample was then returned to the screen and rubbed between thumb and forefinger under a water stream adjusted to deliver 150 to 200 mL in 5 s. The sample was returned to the syringe and the volume of fiber remaining was reported as rubbed fiber as a percentage of the initial volume. Duplicate subsamples were analyzed and average values reported. Soil pH was determined in 0.01 *M* $CaCl_2$.

Histosol Taxonomy

For classification in *Soil Taxonomy* (Soil Survey Staff, 1999), organic portions of Histosol and Histel pedons are divided into three tiers rather than horizons. For most soils, the surface tier is 0 to 30 cm, the Subsurface tier is 30 to 90 cm, and the bottom tier is 90 to 130 cm. If the upper 60+ cm is sphagnum, the tiers are 0 to 60 cm, 60 to 120 cm, and 120 to 160 cm. The control section for most Histosols is 0 to 130 cm, or 0 to a mineral or lithic contact <130 cm. If the upper 60 cm is ≥75% (v/v) Sphagnum, the control section is 0 to 160 cm, or 0 to a contact <160 cm (Soil Survey Staff, 1999). Assignment to a suborder focuses on the state of decomposition in the Subsurface tier. Two criteria, rubbed fiber (a measure of physical decomposition) and SPEC (a measure of chemical decomposition) are used to designate each sample as fibric, hemic, or sapric material. Fibric material has >75% (v/v) fiber after rubbing, or has 40% (v/v) or more fiber after rubbing and a SPEC (value/chroma) of 7/1, 7/2, 8/1, 8/2, or 8/3. Hemic material is intermediate in degree of decomposition between fibric and sapric materials. Sapric material has ≤16% (v/v) rubbed fiber, and the SPEC color is below or to the right of a line drawn to exclude blocks 5/1, 6/2, and 7/3 (Munsell designations). All other organic materials are hemic.

RESULTS

Average rubbed fiber was in the hemic range for pedons taken from throughout the Tongass in the present study, but was in the sapric range for pedons from the Stikine area taken for the Tongass soil survey (Table 1). The horizons show a pattern of little decomposed material at the surface and increasing decomposition below this layer. This decomposition pattern is typical in natural, undrained Histosols in the area, as most surface horizons are fibric or in the upper range of hemic materials.

All six pedons from the Tongass soil survey were classified as Cryosaprists according to the fiber analysis. Rubbed fiber contents ranged from <1 to 56% (v/v) and most SPEC colors affirmed [13 of 16 samples] decomposition states indicated by rubbed fiber (Table 1). Three pedons were in the Kina series, two in the Maybeso series, and one was undesignated (Table 2). The Stikine Plot 554 pedon was on the borderline between hemic and sapric materials with 18% (v/v) fiber and SPEC of 6/3.

The classification of pedons from the additional samples from throughout the Tongass was based on the rubbed fiber volume and pyrophosphate color in the control sections (Table 1). In general, SPEC colors indicated greater decomposition than the fiber analysis (Table 1). Several samples with low fiber contents had fibric SPEC colors, suggesting that they may be limnic (Soil Survey Staff, 1999). Conversely, several samples with high fiber contents had sapric SPEC (Table 1), but the majority of the samples with <40% (v/v) rubbed fiber content had sapric SPEC.

Bulk density increases with increasing mineral content (Fig. 2A, $r^2 = 0.51$), but remains fairly constant once the mineral content is subtracted from the organic framework (Fig. 3A, $r^2 = 0.01$). The average bulk density of the samples is 0.17 g cm^{-3} with mineral material and 0.12 g cm^{-3} for the organic framework. The bulk density rises rapidly as mineral content rises above 70% (w/w) (Fig. 2A). The bulk density, mineral content, and fiber content relationships agree with the original work by Lynn et al. (1974). Bulk density tends to increase as fiber decreases (Fig. 2B, $r^2 = 0.18$), but the effect is diminished by removal of mineral content (Fig. 3B, $r^2 = 0.05$).

Reaction classes also apply to the control section for Histosols (Soil Survey Staff, 1999, p. 832). Reaction classes were used to differentiate soils at the family level in the Tongass soil survey. All of the soils evaluated in this study have been arrayed in their family along with Subgroup and series for comparison (Table 2).

DISCUSSION

Soil Properties, Hydrology, and Peat Accumulation

Classification into suborders is based on the premise that physical and chemical states of decomposition coincide, and that fiber and pyrophosphate tests will confirm one another. The rationale may prove true in stagnant water venues, but does not work well in the sloping terrain of southeast Alaska. Numerous papers indicate dissolved organic matter is mobile in soils and groundwater (Murphy et al., 1989; Dalva and Moore, 1991; David and Vance, 1991; Wassenaar et al., 1991) and can be influenced by macropore flow (Jardine et al., 1990). Frazier and Lee (1971) noted possible translocation of C downward in drained agricultural Histosols in Wis-

Table 1. Organic soil properties for sites (pedons) for all organic soils sampled in the Tongass National Forest, southeast Alaska. Control sections are in italics.

Site ID	Depth	Fiber content: Unrubbed	Fiber content: Rubbed	SPEC	Moist soil color†	Decomposition state	Bulk density	Mineral content	pH, 0.01 *M* $CaCl_2$	Slope	Pedon classification by soil taxonomy
	cm	%	%	10 YR			g cm^{-3}	%		%	
Falls Creek 283‡	*0–46*	20	16	5/3	2/1	Sapric	NA§	67	4.9	15–20	euic Terric Cryosaprist
	46–102	TR¶	TR	5/4	2/2	Sapric	NA	93	4.9		
Kake 250‡	*10–58*	32	8	3/4	2/0	Sapric	NA	51	4.7	25–30	euic Terric Cryosaprist
Stikine Kina 555‡	0–10	44	28	7/4	3/2	Hemic	NA	16	4.3	NA	dysic Typic Cryosaprist
	10–36	36	18	7/3	3/2	Hemic	NA	17	3.8		
	36–89	40	10	6/3	2/2	Sapric	NA	14	3.8		
	89–152	28	14	7/2	2/2	Hemic	NA	5	3.9		
Stikine Kina 554‡	0–10	60	52	8/2	4/3	Fibric	NA	7	3.4	NA	dysic Typic Cryosaprist
	10–30	34	20	7/3	2/2	Hemic	NA	16	3.6		
	30–330	34	18	6/3	2/2	Sapric	NA	8	3.5		
Brownson Island 1‡	0–23	46	36	7/3	2.5/1	Hemic	NA	12	4.3	5–10	dysic Terric Cryosaprist
	23–53	24	10	4/3	2/1	Sapric	NA	18	4.1		
	53–94	36	8	3/3	2/1	Sapric	NA	16	4.3		
Brownson Island 2‡	0–15	80	56	8/2	2.5/2	Fibric	NA	4	3.5	0–2	dysic Typic Cryosaprist
	15–51	42	24	8/3	2.5/2	Hemic	NA	9	4.0		
	51–130	36	8	6/3	2.5/2	Sapric	NA	10	3.6		
Totem 1	0–7	84	60	8/1	8/1	Fibric	NA	NA	3.8	2–5	dysic Lithic Cryohemist
	7–30	72	48	8/2	8/2	Fibric	0.17	1	2.9		
	30–49	48	26	5/4	5/4	Hemic	0.17	17	3.3		
Lithic	*49–70*	96	56	7/3	3/2	Hemic	0.16	3	3.1		
Totem 2	0–20	84	64	7/2	6/8	Fibric	0.12	4	4.3	2–5	euic Terric Cryohemist
	20–40	64	20	6/3	2/2	Hemic	0.20	9	5.7		
	40–72	68	48	6/4	3/3	Hemic	0.21	8	4.5		
Terric	*72–100*	64	12	4/3	2/1	Sapric	0.17	17	4.3		
Point Barrie 1	0–8	100	84	8/1	4/3	Fibric	0.07	2	3.5	5–10	dysic Lithic Cryohemist
	8–16	84	60	5/4	2.5/2	Hemic	0.14	8	3.3		
	16–30	68	44	3/2	2/1	Hemic	0.24	15	3.3		
	30–58	60	30	2/2	2/1	Hemic	0.23	7	3.6		
Lithic	*58–76*	46	36	3/4	2/1	Hemic	0.26	14	4.0		
Point Barrie 2	0–12	84	64	7/2	4/3	Fibric	0.07	12	3.5	5–10	dysic Lithic Cryohemist
	12–24	62	58	3/2	2/2	Hemic	0.17	13	3.5		
	24–38	54	32	3/4	2/2	Hemic	0.32	11	3.7		
Beaver Creek	*23–45*	88	48	6/3	3/2	Hemic	0.15	29	4.1	0–2	euic Typic Cryofibrist
	45–88	96	50	7/2	2/2	Fibric	0.10	21	5.5		
	88–130	84	52	8/2	2/2	Fibric	0.10	2	3.9		
Airway	0–5	100	76	7/3	3/2	Fibric	0.08	2	2.8	2–5	euic Terric Cyrohemist
	5–16	64	54	6/3	2/2	Hemic	0.16	10	3.2		
	16–32	68	44	6/3	2.5/2	Hemic	0.14	7	3.5		
50/50 Hem/Fib	*32–62*	90	80	7/3	2/2	Fibric	0.13	8	5.6		
	62–84	68	50	6/3	2/2	Hemic	0.11	12	6.1		
Terric	*84–112*	68	56	5/3	2/2	Hemic	0.22	13	5.9		
Lancaster	0–8	86	82	8/1	3/4	Fibric	0.09	3	3.4	2–5	euic Lithic Cryohemist
	8–22	74	46	7/3	2/2	Hemic	0.16	6	3.7		
	22–31	68	28	5/3	2/1	Hemic	0.17	11	4.5		
	31–57	84	66	7/3	2.5/2	Hemic	0.14	11	4.8		
Lithic	*57–80*	74	48	7/3	2.5/2	Hemic	0.18	46	5.4		
Totem 3	0–5	88	80	8/2	2/2	Fibric	0.11	3	3.5	2–5	dysic Lithic Cryohemist
	5–14	80	62	8/2	3/2	Fibric	0.15	10	3.1		
	14–33	38	16	5/4	3/1	Sapric	0.22	9	3.0		
	33–42	60	28	4/4	2/1	Hemic	0.18	15	3.1		
Lithic	*42–60*	60	46	2/2	2/1	Hemic	0.20	12	3.1		
Starrigavan	0–7	88	82	8/1	4/4	Fibric	NA	NA	4.4	0–2	dysic Typic Cryofibrist
	7–19	50	42	7/4	2/1	Hemic	0.09	4	3.8		
	19–44	84	68	8/1	5/8	Fibric	0.10	1	3.5		
	44–80	88	80	8/1	4/6	Fibric	0.10	2	3.3		
	80–112	72	50	8/2	3/6	Fibric	0.12	4	3.8		
	112–132	60	40	7/3	3/4	Hemic	0.10	12	3.9		
Margaret Lake	0–10	50	32	8/2	2/1	Fibric	0.14	11	5.0	2–5	euic Terric Cryohemist
	10–36	58	42	8/1	2/1	Fibric	0.07	8	5.2		
	36–74	62	34	5/3	2.5/1	Hemic	0.13	50	5.0		
Terric	*74–85*	44	22	4/3	2.5/1	Hemic	0.33	81	5.3		
Staney 1	2–12	32	20	5/4	2/1	Hemic	0.13	14	5.2	0–2	euic Terric Cryohemist
	12–24	63	32	5/3	2/2	Hemic	0.13	10	4.9		
	24–46	57	29	6/4	2/2	Hemic	0.17	15	4.9		
	46–72	76	48	7/3	2.5/3	Hemic	0.15	8	4.9		
Terric	*72–105*	NA	NA	NA	2/1	NA	0.21	13	4.9		
Staney 2	0–3	44	25	7/4	NA	Hemic	0.15	13	5.7	0–2	euic Typic Cryohemist
	3–12	60	8	7/2	2/1	Sapric	0.13	18	6.1		
	12–21	62	28	5/4	2/1	Hemic	0.17	16	5.8		
	21–40	76	25	6/4	2.5/2	Hemic	0.15	13	5.8		
	40–93	58	38	6/3	2.5/3	Hemic	0.14	16	5.8		
	93–132	48	24	7/3	2/1	Hemic	0.13	18	6.0		

Continued on next page.

Table 1. Continued.

Site ID	Depth	Fiber content		SPEC	Moist soil color†	Decomposition state	Bulk density	Mineral content	pH, 0.01 *M* $CaCl_2$	Slope	Pedon classification by soil taxonomy
		Unrubbed	Rubbed								
	cm	%		10 YR			g cm^{-3}	%		%	
Fruit Loop	0–10	86	76	8/1	4/6	Fibric	0.03	3	3.4	15–20	dysic Terric Cryosaprist
	10–25	48	32	7/4	2/2	Hemic	0.08	20	3.9		
	25–45	64	28	7/4	2.5/2	Hemic	0.10	10	3.9		
	45–65	40	16	6/3	2/1	Sapric	0.15	7	4.1		
	65–78	40	4	4/4	2/2	Sapric	0.12	8	4.3		
Terric	*78–89*	20	12	4/4	2/2	Sapric	0.64	74	4.3		
Salamander	0–7	NA	NA	8/1		NA	NA	NA	3.5	15–20	euic Typic Cryosaprist
	7–20	72	12	4/3	2/1	Sapric	0.17	21	3.5		
	20–44	68	24	7/3	3/2	Hemic	0.16	13	3.4		
	44–70	8	6	4/4	2/2	Sapric	0.31	42	3.9		
	70–109	24	12	6/4	3/2	Sapric	0.24	55	4.1		
	109–139	NA	NA	5/4	3/2	NA	NA	NA	4.5		
	139–169	48	28	NA	2.5/2	Hemic	0.13	10	4.0		
	169–213	28	16	NA	2/2	Sapric	0.25	34	4.0		
Eaglecrest 1	0–16	56	40	8/2	5/4	Fibric	0.08	7	3.4	0–5	dysic Terric Cryohemist
	16–33	40	24	8/3	3/3	Hemic	0.09	13	3.3		
	33–60	48	32	6/3	2.5/1	Hemic	0.12	12	3.2		
	60–84	60	44	8/3	1.5/2	Fibric	0.18	6	3.3		
Terric	*84–102*	24	12	5/3	3/3	Sapric	0.26	57	3.7		
Eaglecrest 2	0–10	40	28	6/3	2.5/2	Hemic	0.09	17	4.3	5–10	dysic Terric Cryohemist
	10–23	24	8	6/3	3/2	Sapric	0.19	52	4.2		
	23–31	24	20	5/4	3/2	Hemic	0.21	47	4.1		
Terric	*31–51*	32	20	5/3	3/2	Hemic	0.31	75	4.2		
Deer Creek 1	0–8	53	43	6/4	5/4	Hemic	0.23	40	6.3	2–5	euic Terric Cryohemist
	8–20	68	41	7/3	2/2	Hemic	0.20	46	5.9		
	20–39	66	44	5/4	2/2	Hemic	0.23	54	5.5		
	39–63	58	33	4/2	2/2	Hemic	0.18	41	5.2		
Terric	*63–80*	37	22	4/4	2/2	Hemic	0.35	56	5.0		
Deer Creek 2	0–8	80	78	3/4	3/4	Fibric	0.13	2	3.3	2–5	dysic Typic Cryohemist
	8–27	70	38	2/2	3/3	Hemic	0.12	3	3.3		
	27–40	70	54	2/2	3/4	Hemic	0.17	2	3.2		
	40–70	69	48	2/2	4/4	Hemic	0.12	2	3.3		
	70–115	59	40	3/3	4/4	Hemic	0.13	10	3.7		
	115–150	32	20	3/2	3/4	Hemic	0.24	55	4.3		
	150–200	56	36	3/2	3/2	Hemic	0.19	18	4.6		
Three Lakes	2–5	66	34	5/4	2.5/2	Hemic	NA	NA	3.7	15–20	dysic Typic Cryohemist
	4–24	46	20	4/3	2.5/1	Hemic	0.25	37	3.7		
	24–50	58	34	6/3	3/3	Hemic	0.17	15	3.5		
	50–95	58	32	7/3	4/4	Hemic	0.15	8	3.5		
	95–135	52	23	6/3	3/4	Hemic	0.15	2	3.5		
	135–205	48	25	6/3	3/3	Hemic	0.12	2	3.7		
Zarembo	0–4	43	28	7/3	3/2	Hemic	NA	NA	5.2	0–2	euic Terric Cryohemist
	4–19	50	28	5/3	2.5/2	Hemic	0.12	14	4.5		
	19–49	53	31	5/3	3/2	Hemic	0.13	21	4.1		
	49–75	29	13	4/3	2.5/1	Sapric	0.18	29	4.4		
Terric	*75–87*	34	26	4/3	2.5/2	Hemic	0.15	33	4.6		
Wrangell 1	0–11	82	78	8/1	2.5/2	Fibric	0.09	8	3.1	20–25	dysic Terric Cryohemist
	11–26	76	20	7/3	2/1	Hemic	0.22	18	3.1		
	26–53	82	26	5/4	2/2	Hemic	0.15	4	3.3		
Terric	*53–70*	60	36	5/4	2.5/2	Hemic	0.18	38	3.0		
Wrangell 2	0–7	98	80	8/1	3/2	Fibric	0.10	3	3.0	5–10	dysic Typic Cryofibrist
	7–15	54	20	6/3	2.5/2	Hemic	0.17	9	3.0		
	15–22	96	48	8/3	2.5/2	Fibric	0.10	3	3.0		
	22–45	72	52	8/3	2/1	Fibric	0.12	3	3.0		
	45–90	94	68	8/2	4/4	Fibric	0.08	3	3.2		
	90–130	68	40	8/2	3/3	Fibric	0.13	4	3.3		
Thorne Bay 1	0–8	64	44	8/3	2.5/1	Fibric	0.09	3	3.4	0–5	euic Typic Cryohemist
	8–33	70	28	7/4	2.5/1	Hemic	0.13	3	3.0		
	33–63	78	36	8/3	3/3	Hemic	0.09	3	3.6		
	63–85	68	32	7/4	3/2	Hemic	0.10	3	3.3		
	85–125	64	28	7/4	3/1	Hemic	0.12	7	4.3		
	125–150	51	29	7/2	2.5/1	Hemic	0.18	10	4.5		

† Value/Chroma.
‡ Tongass Soil Survey Information.
§ NA = not available.
¶ TR = trace.

consin. We think large fluxes of water move down steep hillslopes and provide a greater opportunity for the movement of soluble C into soils with hemic and fibric fiber contents. Anaerobic conditions retard decomposition and lead to the formation of organic soils in saturated places on the landscape. Aerobic decomposition is more efficient and results in the accumulation of considerably less organic matter. It is likely that rapidly moving water on steep slopes in the Tongass is aerated, decomposition is relatively high, and the products are transported down slope.

Although the rubbed fiber is >16% (v/v) in most

Table 2. Family and series classifications for established organic soil series in the Tongass National Forest and pedon classification for sampled southeast Alaskan soils based on soil taxonomy.

Subgroup	Family	Series	Pedon classification by soil taxonomy
Cryic Sphagnofibrists	euic		Beaver Creek
	dysic	Kogish	
Typic Cryofibrists	euic		
	dysic		
Terric Cryofibrists	euic		
	dysic		
Lithic Cryofibrists	euic		
	dysic		
Typic Cryohemists	euic		Staney 2
	dysic	Kina	Starrigavan, Wrangell 2, Three Lakes
Terric Cryohemists	euic		Airway, Margarita Bay, Staney 1, Deer Creek 2, Zarembo, Totem 2, Deer Creek 1
	dysic		Eaglecrest 1, Eaglecrest 2, Wrangell 1
Lithic Cryohemists	euic		Lancaster
	dysic	Grindall	Totem 1, Point Barrie 1, Point Barrie 2, Totem 3
Typic Cryosaprists	euic	Karheen	
	dysic	Kushneahin	Salamander, Stikine 555, Stikine 554, Brownson Island 2
Terric Cryosaprists	euic	Maybeso	Falls Creek, Kake
	dysic		Fruitloop, Brownson Island 1
Lithic Cryosaprists	euic	Kaikli	
	dysic		

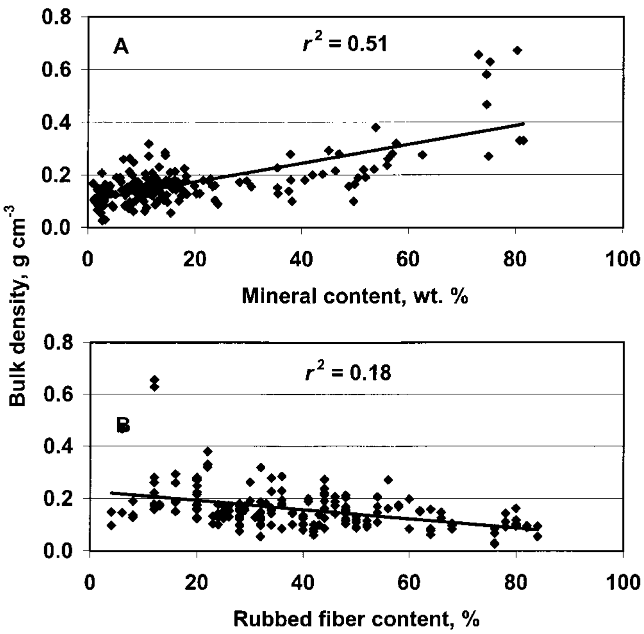

Fig. 2. Bulk density as a function of mineral content (A) and rubbed fiber content (B) in soil samples taken from throughout the Tongass National Forest, southeast Alaska.

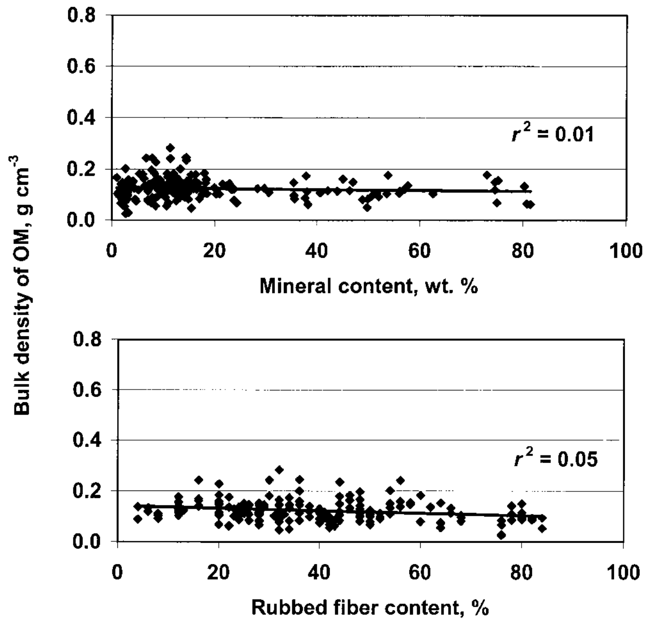

Fig. 3. Bulk density of the organic matter as a function of mineral content (A) and rubbed fiber content (B) in soil samples taken from throughout the Tongass National Forest, southeast Alaska.

samples, SPEC darkens with depth in several profiles, indicating an increase in dissolved organic matter (Table 1). The SPEC is often sapric when the fiber content is hemic, or even fibric. We think sapric material may accumulate through transport via water flowing downslope through the soil as well as in situ decomposition of the organic material. Most of the colors of the samples are sapric, and it is difficult to discern a pattern of SPEC color associated with slope. The moist soil colors are almost exclusively sapric colors and also indicate that most of the organic horizons have dissolved organic material (Table 1). Sodium pyrophosphate extract color tends to darken from Typic to Terric to Lithic subgroups in line with the thickness of the peat. The hydrologic dynamics near the terric and lithic contact may concentrate dissolved organic matter by perching water on top of mineral soil or rock and bring solutes from the underlying mineral material into the peat.

Our bulk density data contradict findings of an extensive peat study in Minnesota, Wisconsin, and Michigan (Boelter, 1969; Nichols and Boelter, 1984). Boelter (1969) showed bulk densities of <0.075 g cm^{-3} for fibric materials, >0.195 g cm^{-3} for sapric, with hemic materials in between. In our study, average bulk density of fibric materials equals 0.11 g cm^{-3}, and the average of sapric and hemic materials equals 0.13 g cm^{-3}. In the previous studies, core samples were collected. In this study, samples were carved into cubes 5 cm on a side. This should be taken into consideration in evaluating the different results. However, we feel that the overall differences are too large to be accounted for by sampling alone. The overall average bulk density of the organic framework in our study was also higher (0.12 g cm^{-3}) than the values reported by Lynn et al. (1974) (0.07 g cm^{-3} to 0.08 g cm^{-3}). Nichols and Boelter (1984) divided the fiber samples into size classes and showed that the fibers >2 mm had very low bulk densities, and materials <0.1 mm had very high bulk densities. They attributed differences in bulk density to differences in the density of decomposing plant matter and compaction of the peat from fluctuating water tables (Nichols and Boelter, 1984). The present data do not fit this pattern well and the mechanisms in the soils of southeast Alaska are unclear.

The hydraulic conductivity in hemic and sapric material depends on the degree of decomposition, and distinctions between the two provide valuable hydrologic information (Boelter, 1969; Boelter and Verry, 1977). Southeast Alaska offers a much different hydrologic setting than the upper Mississippi bog systems with low slopes and hydraulic gradients studied in previous work (Boelter, 1969). Southeast Alaskan slopes have much higher hydraulic gradients either on site or surrounding the peatlands. There is a trend in decomposition and slope with more sapric material in slopes >15% (Table 1). Slope gradient is probably the most important influence on water flow through southeast Alaskan soils. Decomposition is enhanced during low flow periods when the organic material is less saturated. This hydrologic influence on organic (or mineral) soil characteristics on slopes could be useful in refining soil delineations.

Organic matter decomposition is closely associated with soil saturation and variable saturation levels within profiles leads to differential peat decomposition. Differences in hydraulic conductivity may provide preferential pathways for lateral flow in organic soils with important implications for hillslope hydrology (Ingram, 1981). Estimates of water flow through the soils may be underestimated during low flow if a sapric decomposition pattern is assumed.

Field Application of Sapric and Hemic Distinctions

The organic soils of the Tongass are part of a vegetation mosaic that includes forested mineral soils, forested organic soils, and nonforested peatland. The organic soils were not intensively sampled during the soil survey because they did not support dense forest vegetation. The focus of the survey was on productive forestland. Strong soil–vegetation relationships were assumed when the Tongass soil survey was initiated in 1961 (Stephens et al., 1969; Krosse, 1993). However, the use of vegetation to separate hemists from saprists in map units does not seem to work. Peat accumulates with time from several vegetation communities, and each contributor brings a distinct decomposition pattern. Vegetative distinctions among forest, fen, and bog environments provide convenient botanical classes of vegetation communities on organic soils, but may not be well associated with the degree of peat decomposition (Swanson and Grigal, 1989). Only current vegetation is used in mapping and may not coincide with peat that has accumulated with time. There is not a good relationship between vegetation and a saprist or hemist soil distinction.

Initial survey work on the Tongass established four groups of organic soils below the alpine (Stephens et al., 1970). They noted that only Maybeso and Kaikli soil series supported forest vegetation. These soils were described as mucks over peats. The deep, moderately decomposed Kina, Kogish, and Staney series support sphagnum moss, sedges, low shrubs, forbs, and scattered open-grown trees. The Maybeso and Kaikli soils were classified as Cryosaprists, Kina as Cryohemists, Staney as Cryofibrists, and Kogish as Sphagnofibrists based on field estimates of fiber.

Saprists and hemists were difficult to distinguish; therefore, organic soils were often mapped in complexes of series that included the forested Maybeso, Kaikli (Cryosaprists), and Kushneahin (Cryohemists), and the nonforested Kina and Kogish series (Cryohemists). These series were based on field observations, field fiber tests, and laboratory fiber and SPEC tests. These data (Table 1) supported Maybeso as saprist, while lab analyses of Kina samples indicated both sapric and hemic peat. Maybeso and Kaikli were mapped in complex with Kina soils because there was no difference in use and management of the hemic and sapric soils (Everett Kissinger, 1998, personal communication). The Kina series was mapped in areas that did not support forest vegetation. The Kushneahin series was established as the corollary to the Kina and mapped in areas that did support forest vegetation.

Hemist and saprist corollaries to the Maybeso and Kaikli series were recognized, but differences in vegetation or hydrology between them were difficult to distinguish in the field. There was neither enough pedon information to establish the corollaries, nor a compelling reason to further delineate the organic soils during mapping (Everett Kissinger, 1988, personal communication). The relationships among vegetation, hydrology, and peat decomposition were poorly developed and could not improve the description and delineation of organic soils.

Fiber content information in this study provides relative proportions of hemic and sapric material in the forested organic soils on the Tongass. The pedons can have hemic and sapric horizons, but the subsurface tiers are dominantly hemic. Many of the forested organic soils that resemble the Maybeso and Kaikli series sampled in this study are hemists, with more rubbed fiber than allowed in official series descriptions (Table 2). The underestimation of fiber during the original survey probably led to the perception that the Maybeso and Kaikli series were dominated by sapric material. Fiber is often underestimated in the field because fibers are masked by accumulations of sapric material. Our data show that forests grow on deep hemists (Kina series), as well as on saprists. The prevalence of hemists in our data set indicates that hemists may dominate the Cryosaprists-Cryohemists mapping units.

Mapping Applications of Sapric and Hemic Distinctions

In the Cooperative Soil Survey, a series cannot range beyond limits of the family or other higher categories of soil taxonomy. Map units can contain components of series (similar or dissimilar) other than the one used to name the unit. However, map units can be designed at higher taxonomic levels; family and subgroup, for example. Complexes of Cryohemists and Cryosaprists (suborder distinction) in Typic, Lithic, and Terric subgroups appear to be the most reliable and reasonable map units on forested organic soils in southeast Alaska. Our results suggest that map units of organic soils based on higher taxonomic categories may be a practical and appropriate means of identifying organic soil properties in the field.

Subgroup classes and reaction families could provide additional descriptive information for organic soils. A subgroup class for Cyrosaprists or Cryohemists would be valuable in identifying pedons that have significant fibric, hemic, or sapric peat accumulation. *Soil Taxonomy* (Soil Survey Staff, 1999) provides Sapric and Fibric subgroup classes for Haplohemists, but none for Cryohemists. The subgroup modifier identifies pedons that have >25 cm of sapric or fibric materials in the control section. Suborders are based on the Subsurface tier in most cases, while subgroups are determined on the control section below the surface tier (i.e., subsurface and bottom tiers). However, the application of the subgroup is limited, as the Lithic and Terric subgroups come before Hemic subgroups. Therefore, only the Typic subgroups could have the Hemic, Sapric, or Fibric subgroup classes. Stikine 555 is the only example that would be changed to a Hemic Cryosaprists in the present study (Table 1).

Reaction families could be based on the surface and subsurface tiers in place of the entire control section. This would make the reaction classes more similar to the control section in mineral soils. The practical application of reaction classes is for root growth, and very few roots are found in the bottom tier. The Salamander and Thorne Bay 1 soils are examples that are euic because one horizon in the bottom tier is ≥pH 4.5 (Table 2). The surface of these soils is definitely more acidic than the euic description implies (Table 1). If these soils were classified as dysic, they would also be in line with existing Tongass soil series.

The hemic fiber component of these map units should be considered when estimating carbon sequestration by forested organic soils. A previous estimate of carbon in organic soils used a mean of 53 kg m^{-2} for soils mapped as deep Lithic and Terric Cryosaprists, while deep hemic accumulations were estimated at 239 kg m^{-2} (Alexander et al., 1989). These estimates may underestimate the carbon storage in the Lithic and Terric Cryosaprists consociations due to the possible high content of hemic materials. The consociations of Maybeso and Kaikli soils can have deeper and less decomposed organic material than indicated by the mapping unit description. New estimates for these areas should be derived using the Typic, Terric, and Lithic Cryosaprists or Cryohemists mapping combination suggested above.

CONCLUSIONS

Fiber contents in several soil series sampled in this study were higher than indicated in official series descriptions of the Maybeso and Kaikli soils in southeast Alaska. Physical decomposition of the fibers is in the hemic range while chemical decomposition (SPEC) indicates that soluble carbon is transported into organic horizons via water flow downslope. The fiber is less decomposed in the surface layers of peat and becomes more decomposed at depth near the mineral or lithic contact. Hemic and Sapric subgroup classes and reaction families based on the surface tier can provide additional descriptive information for the elaboration of organic soil mapping units and their interpretation. The fiber decomposition data can be used to determine the occurrence of hemic and sapric soils on the landscape and aid in refining estimates of carbon storage in these soils.

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